63-3-2

Final Report, Contract No. FAA/BRD-401
HSR-RR-62/8-MK-X

SUITABILITY OF THE C-54 AS AN AIRPORT LANDING AIDS RESEARCH VEHICLE IN THE JET AGE

This report has been approved for general distribution.

January 1963

Project No. 421-11R

Prepared for

Federal Aviation Agency
Systems Research and Development Service

by

HSR
human sciences research inc
FILLMORE AND WILSON BOULEVARD
ARLINGTON 1, VIRGINIA

Final Report, Contract No. FAA/BRD-401
HSR-RR-62/8-MK-X

SUITABILITY OF THE C-54 AS AN AIRPORT LANDING AIDS RESEARCH VEHICLE IN THE JET AGE

January 1963

Project No. 421-11R

Wallace F. Rollins
W. S. Vaughan, Jr.

Human Sciences Research, Inc.
Fillmore and Wilson Boulevard
Arlington 1, Virginia

ACKNOWLEDGMENTS

The names of the people who contributed to this report are listed in Appendix A. Beyond this, the authors especially wish to thank the following people:

Mr. Eugene E. Pazera, Acting Chief, Aircrew and Aeronautical Aids Section, Human Factors Research Branch, Research Division, Systems Research and Development Service, Federal Aviation Agency, arranged and coordinated the C-54/880 comparative flight tests which were conducted as part of this project;

Captains M. K. Osterhout and K. B. Johnson, C-54 pilots, and Captains C. E. Robbins and A. J. Bolster, 880 pilots in the flight tests;

Captain J. A. Frier, Director of Flight Training, Trans-World Airlines, flew many approaches in the TWA 880 simulator in order that an analysis of the 880 pilot's task could be made, and along with Captain T. R. Graybill of TWA, gave us a great deal of help in refining this analysis;

Mr. A. W. Ogilvie, Manager of Simulator Maintenance and Engineering, Trans-World Airlines, coordinated our visit to TWA's Transportation Training Center and was the source of much of our information on the operating routine and performance characteristics of the Convair 880;

Mrs. Luna Wallace prepared the line drawings for this report; and

Mrs. Bette Listman and Mrs. Rose Anna Betts typed the report.

Human Sciences Research, Inc.
Fillmore and Wilson Boulevard, Arlington 1, Virginia
SUITABILITY OF THE C-54 AS AN AIRPORT LANDING
AIDS RESEARCH VEHICLE IN THE JET AGE, W. F. Rollins
and W. S. Vaughan, Jr., January 1963
54 pp., including 7 illustrations, 19 tables, Final Report
(Contract No. FAA/BRD-401)

ABSTRACT

Study purpose was to determine the generality of in-flight evaluations of airport marking and lighting (AML) systems when a Douglas C-54 is used as the test aircraft. The problem was explored from two points of view: first the generality of C-54 flight test results to a specific class of aircraft represented by the Convair 880; and second, the problem of increasing the generality of flight test results through increasing the precision of experimental procedures.

Comparative analyses were made of the Douglas C-54 and the Convair 880 in terms of pilot tasks, cockpit visibilities and approach and landing profiles. Information for these descriptions was obtained through four sources: review of flight manuals and other technical documents, interviews with pilots and pilot training personnel, controlled observation of pilot tasks during approach and landing with TWA's Convair 880 dynamic simulator, and operational flight trials with FAA's C-54 and 880.

Recommendations are made for flight test modifications to increase generality of C-54 results to Convair 880 type aircraft. Experimental procedures to increase the general applicability of flight test results are recommended.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

LIST OF TABLES AND FIGURES (cont.)

I. Introduction

The Research Problem

Airport marking and lighting design proposals are evaluated by Federal Aviation Agency scientific personnel at the National Aviation Facilities Experimental Center (NAFEC) in research settings ranging from laboratory simulation to operational flight. For flight test purposes a Douglas C-54 aircraft has been converted to a research vehicle by NAFEC. This aircraft is instrumented to measure and record several indices of pilot-aircraft system performance. These measures include movement of the primary flight controls (rudder, ailerons, elevators, and throttles), readings of the flight instruments, pitch and roll attitudes, and the dynamic scene as viewed through the windscreen. One of the purposes of this equipment is to record data which reflect the adequacy of the pilot's control of the aircraft in response to proposed marking and lighting designs. A marking or lighting design can be evaluated as superior to another in providing required information on the basis of the speed and appropriateness of test pilot's control responses.

In the interests of test economy, it would be desirable if conclusions based on flight evaluations of marking or lighting systems obtained with a test aircraft were applicable to other types of aircraft. Marking and lighting designs found to be most effective in providing guidance to a pilot in control of the test aircraft would then be known to be most effective when the pilot is controlling any other aircraft. This problem finds current expression in the question of generality of test results obtained with a C-54 to large commercial jet aircraft.

The purpose of the research reported here, therefore, is to determine the limitations on general applicability of airport marking and lighting (AML) evaluations to newer, high-performance aircraft when only the currently instrumented C-54 is used for evaluations; and to suggest, for the limitations identified, techniques which could be used with the C-54 to overcome the limitations.

The problem of generalization of flight test results is examined from two points of view since the instrumented C-54 can be used in two types of evaluations. One is the check-out or operational acceptability testing of an already-developed marking or lighting configuration. The primary objective of this type of evaluation is to assess pilot acceptance of the marking or lighting configuration under operational flight conditions. A second type of evaluation is required in the development of an optimal lighting configuration through field experimentation. The objective of this type of evaluation is to determine functional relationships between changes in the marking or lighting design and concomitant changes in pilot-aircraft system performance. The problem of generalization of results in the first case is one of differences between test aircraft and the aircraft to which results are to be generalized in what the pilot does, what he can see, how quickly he must act, etc. Solutions to the problem would be found essentially in simulating one aircraft with another. If it is desired to test the acceptability of a marking or lighting design to the pilot of a large commercial jet by conducting the test with a C-54, then the solution should be found in arranging test conditions so that the research pilot's task is as similar as possible to the task of the jet pilot.

The problem of generalization of results is quite different when the C-54 is considered as an AML research instrument. The objective of this use of the aircraft is to discover differences in pilot performance which

result from variations in AML design features. Historically, flight performance differences in response to design variations have been difficult to detect. Assuming real differences in the designs tested, this difficulty can be attributed to at least the following factors: (1) insensitivity of the criterion measures and (2) ability of experienced pilots to compensate for inadequacies in marking and lighting configurations. Both of these factors tend to mask the performance differences which are sought in experimentation. They are interrelated problems in that solving one will alleviate the other. If criterion measures can be developed which will tap the efforts which the pilot must exert to compensate for AML design inadequacies, then we need not be so concerned about this compensatory capacity. Conversely, if steps can be taken to minimize the pilot's ability to compensate for AML design inadequacies, then perhaps the criteria presently in use will be sufficiently sensitive to reflect performance differences.

The extent to which experimental results of AML flight tests conducted with one aircraft can be generalized to others depends upon the success of the experimenter in removing effects of aircraft differences from pilot performance measures. Different types of aircraft demand different levels of effort from the pilot. The pilot of a "forgiving" airplane (e.g., C-54) has more excess data-processing capacity, more excess physical response capacity, and more time than does the pilot of the more demanding jet aircraft. As a result the "lightly-loaded" pilot flying to an inferior design has the capacity to compensate, perhaps by making use of extraneous cues in the immediate environment, for the design inadequacies. When approaching a superior design the same pilot needs to exert only the effort demanded by the airplane itself. When this sequence of events occurs the criterion measures could indicate that the two designs are essentially equivalent. The heavily-loaded jet pilot has markedly less capacity to compensate for design inadequacies and, consequently, AML designs which appear to be equivalent when tested with a C-54 may, in fact, be quite different with respect to suitability for

jet operations. Under these conditions the generality of C-54 results is severely limited. A general solution to this problem would be to take steps which insure that the research pilot's task is made at least as difficult as it would be in any aircraft under the most demanding operational circumstances.

Conclusions concerning the generality of test results of either type, operational acceptability or experimentation, rests on the nature of/and the degree of the differences between the operational routine and performance characteristics of the test aircraft and those aircraft to which results are to be generalized. If we wish to imitate a commercial jet aircraft with a C-54 for purposes of operational suitability testing, we need to know how to change it to make it more like a jet and how to fly it to represent a jet approach and landing profile. If, on the other hand, the C-54 is to be used in AML experimentation to develop optimal designs, it is necessary to ascertain that the stressful experimental conditions which are established for the research pilot make his task at least as difficult as that of the pilot of any type of aircraft to which the research results are to be generalized. This is suggested as a minimum. In order to make a substantial increase in the precision and generality of flight test results, the research pilot's tasks should be made as difficult as possible, consistent with considerations of safety.

The Research Approach

The question of generality of flight test results from one aircraft to others was approached through a specific case - the generality of flight test results from Douglas C-54 to Convair 880.[1] This approach has two advantages. First, it provides specific information about an applied problem of

[1] The Convair 880 was selected, since, of the presently operational commercial jet aircraft, it was most different from the Douglas C-54 in landing speed.

current concern to FAA; and second, it provides an example of a general approach which later can be applied to any other aircraft of interest now or in the future.

Differences between the two types of aircraft which would restrict the generality of AML evaluative results obtained with the C-54 are of three types:

Structural characteristics of the aircraft - including controls, cockpit displays, gross weight, and windscreen configuration.

Approach and landing profile - including approach speed, rate of descent, approach angle and attitude.

Pilot tasks - including visual routine, information processing, and manual control.

These classes of differences are significant to the problem of generality of test results with AML designs since they are sources of differences in what the pilot must do, how long a time he has to act and how much of the ground plane he can see during approach and landing.

Three kinds of analyses were made to compare Convair 880 with the Douglas C-54 in those characteristics of the pilot-aircraft interaction which appeared significant to the question of generality of research results. First, a pilot task analysis was conducted to compare pilot work loads and flight techniques. The pilot task analysis for the 880 was based on two sources of information: interviews with 880 pilots of Trans-World and Northeast Airlines, and observation of simulated landings at TWA's Kansas City flight training facility. Pilot task analysis for the C-54 was based on interviews with pilots of Slick Airways in Norfolk, Virginia.[1]

---

1 Appendix A contains a list of pilots interviewed.

Second, an approach and landing profile for the two aircraft was constructed initially on the basis of TWA flight operations manual for the 880 and later refined by data from phototheodolite recordings and on-board pitch and roll recording equipment for both 880 and C-54 aircraft during flight trials at NAFEC. These data were collected for 12 simulated ILS touch-and-go landings with NAFEC's C-54 and 10 similar landings with an FAA 880.[1]

Third, an analysis of cockpit visibility during approach and landing was made for both C-54 and 880 based on windscreen dimensions and pitch data. Windscreen dimensions were obtained from binocular photographs of the C-54 and 880 windscreens taken from the positions of the pilot's eyes and showing the visual angles subtended by the windscreens. Pitch data were obtained during the flight trials at NAFEC.

---

1 Appendix B contains a description of the flight trials.

II. Comparison of 880 and C-54

Pilot Task Analysis[1]

Convair 880

The following description assumes an aircraft gross weight of 130,000 pounds. Reference speed (the speed at which the aircraft should cross the threshold with flaps at 50 degrees) at this gross weight is 142 knots. This description is correct for a TWA 880 making an ILS landing at the Kansas City Airport.

At about a mile or two beyond the outer marker the pilot is primarily concerned with heading control since he does not want to be faced with the necessity, later in the approach, of bracketing both localizer and glide slope at the same time. He is monitoring his flight instruments and using the Flight Path Indicator (FPI) and the Flight Director Command Bar in the Horizon Director Indicator (HDI) to check and correct localizer tracking error. Aileron control (control wheel) is used to get the aircraft lined up with the ILS localizer signal. Altitude and air speed at this point are approximately 1,500 feet above terrain and 160 knots (reference speed plus 20 knots) respectively. These values can vary as much as ± 100 feet and ± 5 knots as the pilot is not as concerned with tight control of altitude and air speed as he is with getting the aircraft set up to track the ILS localizer in preparation for the interception of the glide slope signal. Flaps are set at 30 degrees.

Having set the aircraft up to track the localizer, the pilot continues to scan the flight instruments and maintains reference speed + 20 knots and 1,500 feet altitude by monitoring the air speed indicator and altimeter and by making corrections, if needed, with the throttles (air speed) and the

1 Appendix C contains a tabular presentation of pilot task analysis.

elevator control (altitude).[1] A blinking blue light on the instrument panel and a 400 cps tone in the pilot's headset indicate that the outer marker is being crossed.

Pilot continues to monitor instruments and watches the FPI for the approach of the point of intersection with the glide slope. As aircraft approaches this point (nose of aircraft on FPI touches horizontal bar), pilot orders gear down and flaps 40 degrees (orders are executed by the co-pilot), and the final check list is completed. Aircraft becomes stabilized in this new configuration and the ILS glide slope is intercepted. Pilot then controls elevators (moves control column forward) and horizontal stabilizers (activates trim switch on control wheel) to establish aircraft on glide slope. He must, at this point, ease back on the throttles to compensate for increased air speed caused by the nose-down attitude and to reduce air speed to reference + 10. He attempts to maintain rate of descent at about 700 to 800 feet per minute.

At this point the aircraft is established on the proper heading and glide slope, gear down and locked, final check list is completed, and the pilot has only to "fly the airplane". He continues to scan the flight instruments: HDI to air speed indicator to HDI to altimeter to rate of climb indicator to FPI, etc. He makes small control adjustments in throttle, ailerons, horizontal stabilizers, and elevators as required to maintain command values of heading, glide slope, air speed, and rate of descent. Co-pilot also monitors flight instruments and calls out altitudes.

At approximately 50 feet above ceiling, co-pilot begins to look for the runway. At breakout he may say, "Runway in sight" (in which case the

---

1 Elevator control adjustments are generally followed by the application of stabilizer trim by means of the trim switch on the out-board horn of the control wheel. This procedure eliminates the force being held on the control column, returns the column to the neutral position, and insures that some elevator travel will be available for the purposes of flaring the aircraft.

pilot directs his eyes outside the cockpit and "goes contact"), or he may say, "Minimums - no runway" (in which case go-around procedures are initiated) if the runway is not clearly visible.

In the event that the pilot makes visual contact with the runway, which is the usual case, he continues down the glide slope watching the runway and making periodic quick checks on the flight instruments. Co-pilot also continues to monitor instruments and scans outside, watches for traffic, etc. When the aircraft reaches a point where the pilot sees that he can make the runway with no more power (roughly 150 feet altitude and 1/4 mile from threshold), he orders 50 degrees flaps (executed by the co-pilot) and retards the throttles to achieve boundary speed (reference speed) of 142 knots. Aircraft crosses threshold at approximately 35 feet altitude with about a 3 degree up pitch angle.

Pilot reduces air speed by easing back on the throttles and flares the aircraft to about a 5 degree up pitch angle by pulling back on the control column. The flare combined with entry into ground effect reduces the rate of descent substantially. Flare is initiated somewhere between threshold and 300 feet down the runway depending on the rate of descent. At higher rates of descent pilot will flare sooner.

Aircraft touches down within the first 1/3 of the runway length at 120 to 130 knots, with 50-degree flaps and about a 5 degree up pitch angle.

Douglas C-54

The foregoing analysis, with a few changes, serves also as an accurate description of the C-54 pilot's task in the approach and landing. The differences are as follows:

1. Gross Weight. The maximum gross landing weight for the C-54 is 63,500 pounds. That of the 880 is approximately 133,000 pounds.

2. Air Speeds. At the maximum gross landing weight the reference speed (V_{ref} or 1.3 stall speed) for the C-54 is 105 knots. Reference speed for the 880 at maximum gross landing weight is 140 knots. Both aircraft fly the same relative air speed regime (V_{ref} + 20 knots from entry into traffic pattern to intercept of glide slope; V_{ref} + 10 knots during descent on glide slope; V_{ref} crossing the threshold). The C-54 touches down at about 90 knots whereas the touchdown speed of the 880 is approximately 125 knots.

3. Instruments. The C-54 pilot keeps a close check on his manifold pressure gauge while no engine instrument appears to be of primary importance to the 880 pilot during the approach and landing.

4. Controls. The horizontal stabilizers on the C-54, unlike those on the 880, are fixed. Trim is applied to the elevators, usually by the pilot by means of a manually operated trim wheel on the control pedestal. The corresponding control movement in the 880 is the activation of a thumb switch on the outboard horn of the control wheel.

Flight Director System

One of the strongest impressions to emerge from the interviews with pilots was that the Flight Director Instrument System[1] is a major factor in the success of an ILS approach and landing. Pilots stated that the use of this instrument system increases the accuracy of ILS tracking while, at the same time, reducing the data-processing demands made on the pilot. It would seem, if this is the case, that disallowing the use of the Flight Director would be a logical first step toward increasing the difficulty of the pilot's task for research purposes.

---

[1] For a description of the Flight Director Instrument System see reference #8 (Appendix A), Chapter I, Section 15, pages 3-8.

In order to assess the importance of this instrument system, data were collected during the flight tests on deviations from the ILS localizer and glide slope at breakout (1/2 mile from threshold for the C-54 and 3/4 mile for the 880) when the Flight Director was used and when it was not used. These results are presented in Tables 1, 2, 3 and 4.

Table 1: Deviations from Localizer at Breakout

		C-54 (feet)	880 (feet)
With Flight Director	$\bar{X}$	45.60	25.90
	σ	30.77	16.56
Without Flight Director	$\bar{X}$	155.88	178.00
	σ	96.66	58.00

Table 2: Values of t and p for Differences Between Means

	df	t	p
C-54 with F.D. vs. C-54 without F.D.	11	2.47	$<.05$
880 with F.D. vs. 880 without F.D.	8	5.76	$<.001$
C-54 with F.D. vs. 880 with F.D.	12	1.42	$>.10$
C-54 with F.D. vs. 880 without F.D.	6	3.57	$<.02$
C-54 without F.D. vs. 880 with F.D.	13	3.48	$<.01$
C-54 without F.D. vs. 880 without F.D.	7	.03	$>.50$

Table 3: Deviations from Glide Slope at Breakout

		C-54 (feet)	880 (feet)
With Flight Director	$\bar{X}$	21.44	19.04
	σ	12.44	14.84
Without Flight Director	$\bar{X}$	23.59	25.60
	σ	13.24	3.20

Table 4: Values of t and p for Differences Between Means

	df	t	p
C-54 with F.D. vs. C-54 without F.D.	11	.28	$>$ .50
880 with F.D. vs. 880 without F.D.	8	.56	$>$ .50
C-54 with F.D. vs. 880 with F.D.	12	.30	$>$ .50
C-54 with F.D. vs. 880 without F.D.	6	.41	$>$ .50
C-54 without F.D. vs. 880 with F.D.	13	.58	$>$ .50
C-54 without F.D. vs. 880 without F.D.	7	.19	$>$ .50

It appears, from these results, that the Flight Director makes a significant contribution to control of the aircraft in tracking the localizer but not to control of the aircraft in tracking the glide slope. The results also indicate that the pilot's ability to track the ILS is a function of having or not having the Flight Director instrument rather than a function of the type of aircraft he is flying.

Cockpit Visibility

An important factor to consider in a problem of this type is that of the limitations imposed on the pilot's extra-cockpit vision by the structure of the aircraft. Figures 1 through 5 deal with this consideration (C-54 information is shown in red in all figures). Figure 1 shows the windscreen of the C-54 and that of the 880 as seen from the pilot's position in the cockpit. The drawings are superimposed to permit a direct comparison. In Figure 2 the positions of the pilot's eyes in the C-54 and the 880 are plotted with respect to a common flight deck and instrument panel. The figure shows a profile view of the visual angles subtended at the pilot's eyes by the windscreens of the two aircraft. Figure 3 shows a plan view of the visual angles subtended by the windscreens when the eye positions are plotted with respect to a common instrument panel and aircraft centerline. Figures 4 and 5 show profile views of the pilot's cone of vision and the portion of the ground plane which it covers when the aircraft is in its typical attitude during final approach (Figure 4) and flare-out (Figure 5). Pitch data gathered during the flight tests are presented in Table 5.

Table 5: Mean Pitch Angles of the C-54 and 880 at Selected Points in the Final Approach

	C-54	880	df	t	p
Pitch					
3 miles from threshold	$.1^{\circ}$ down	1.5° up	21	1.80	$>.05$
Middle marker	1.9° down	1.5° up	21	2.06	$>.05$
Threshold	$.8^{\circ}$ up	3.4° up	21	3.82	$<.001$
Flare	2.3° up	4.3° up	17	2.90	$<.01$

Figure 1

C-54 and 880 Windscreens as Seen from the Pilot's Position in the Cockpit

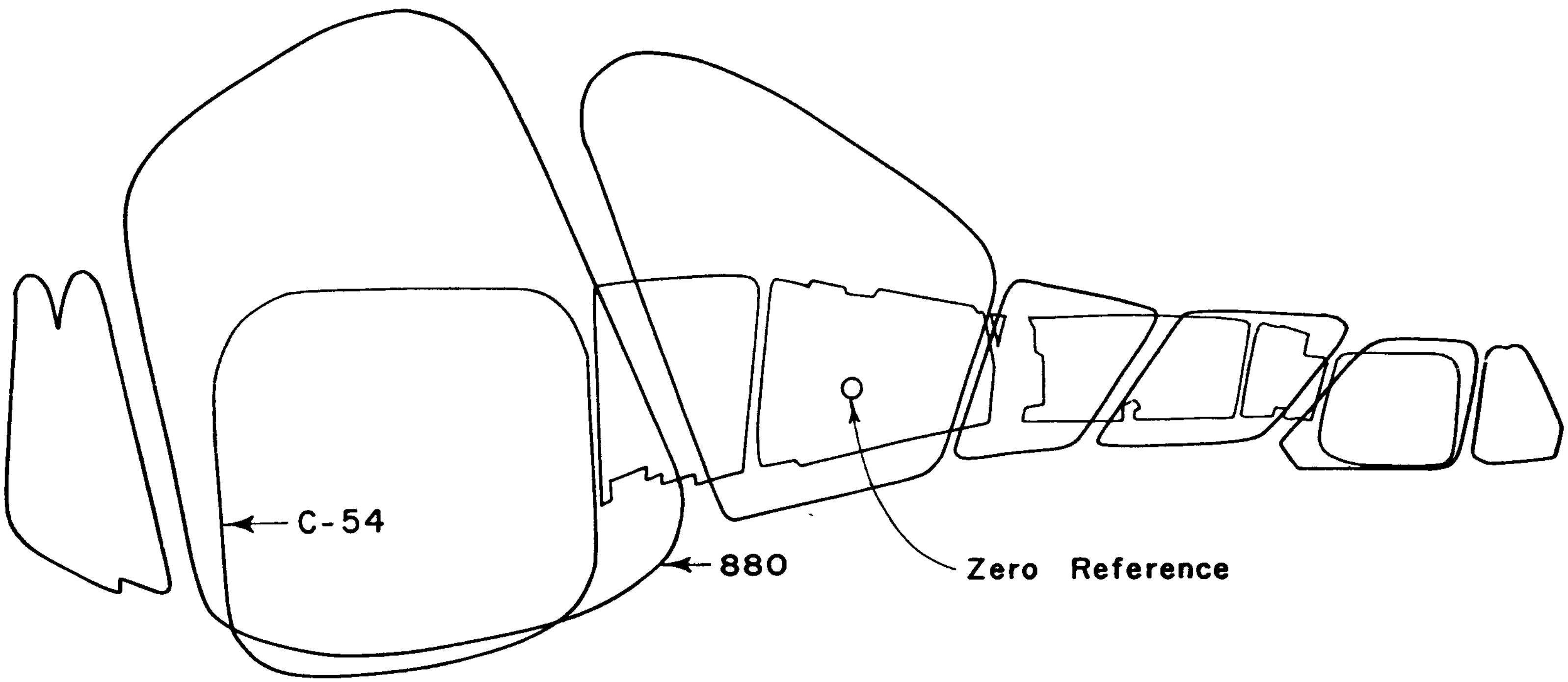


Figure 2

Profile View of the Visual Angles Subtended at the Pilot's Eyes by the Windscreens of the C-54 and 880

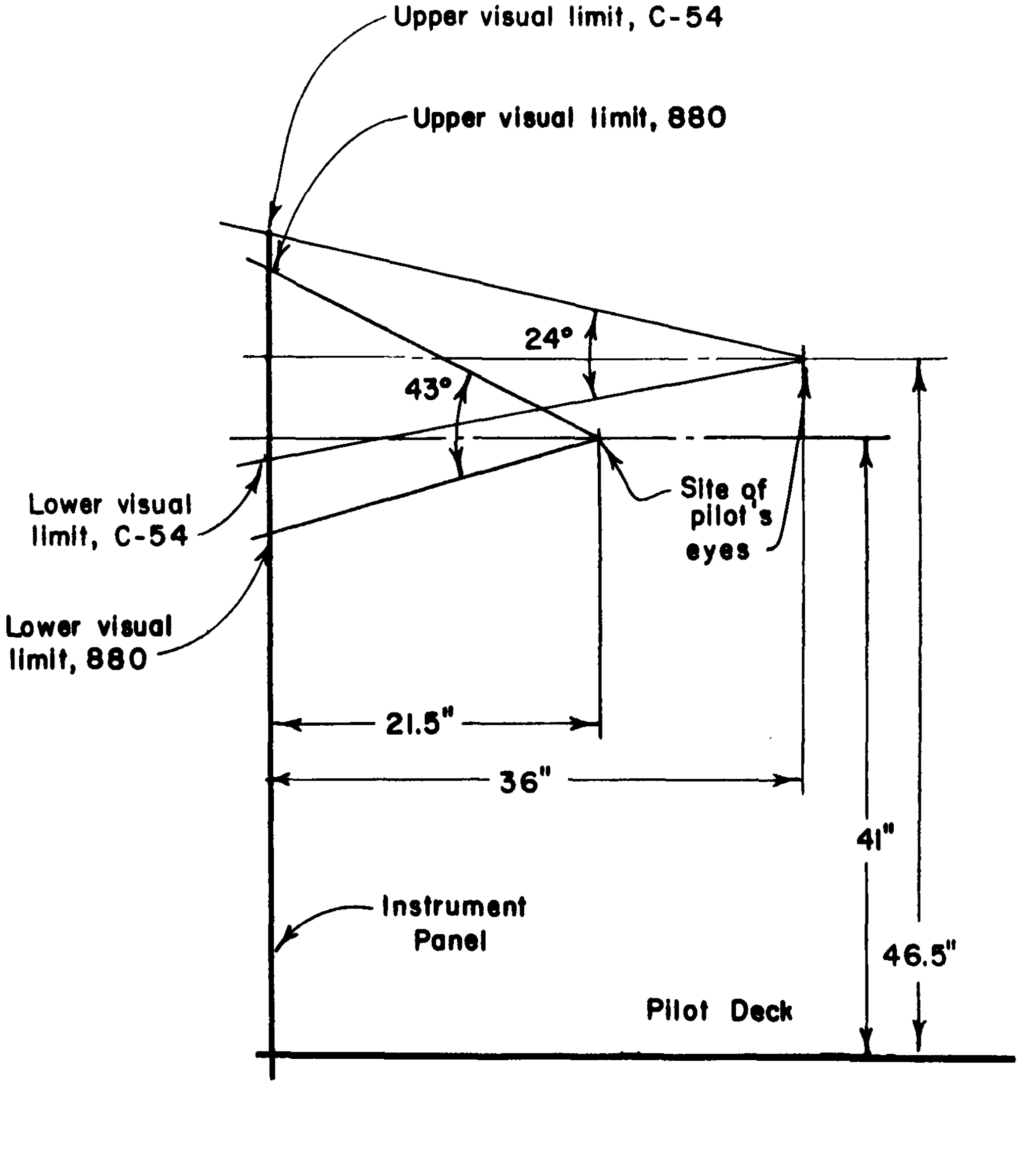


Figure 3

Plan View of the Visual Angles Subtended at the Pilot's Eyes by the Windscreens of the C-54 and 880

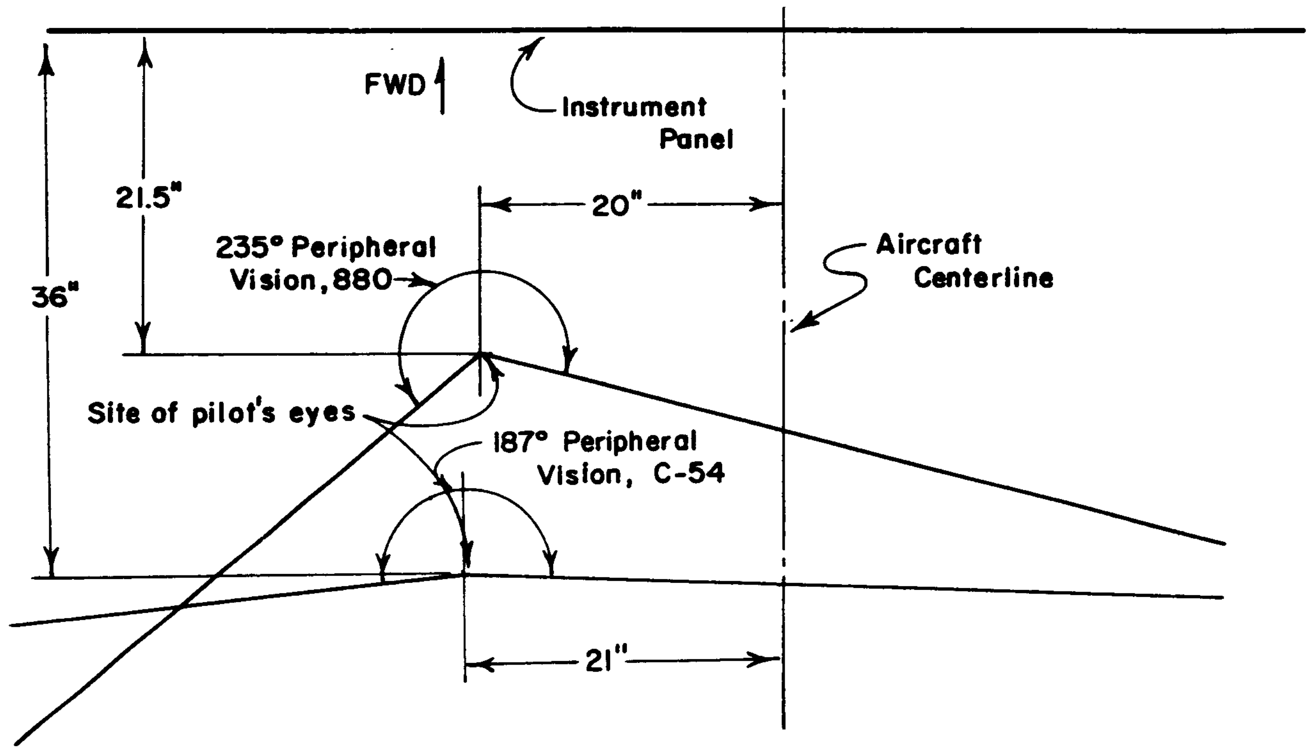
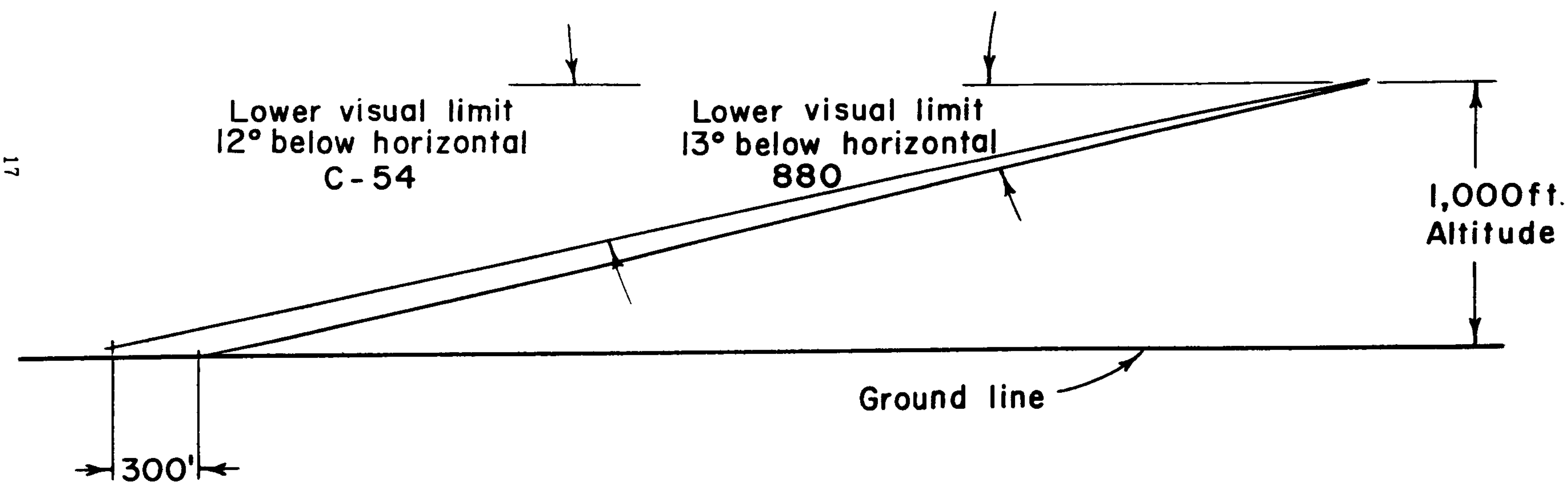
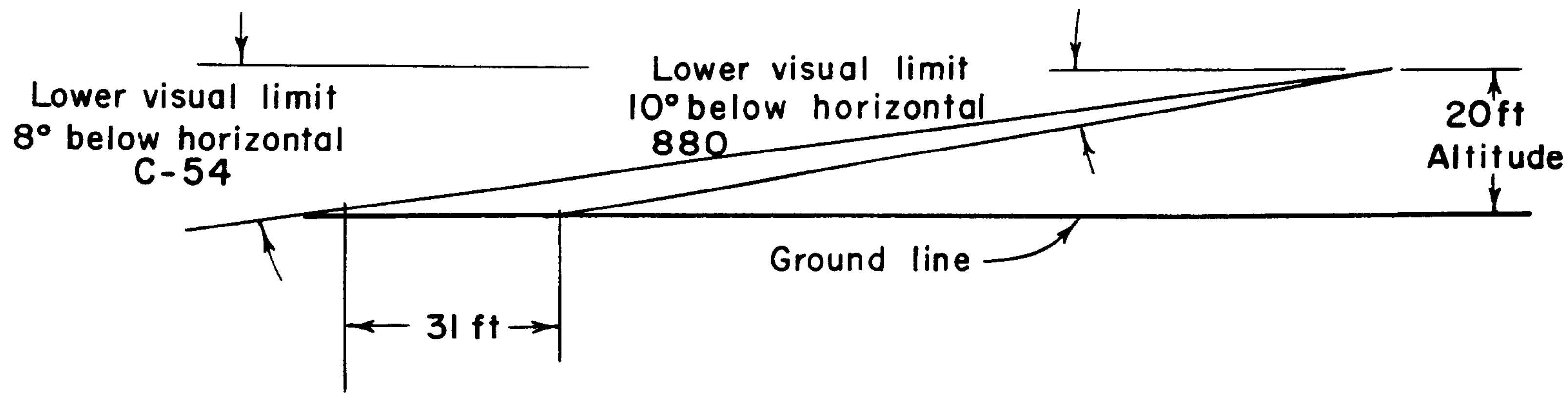


Figure 4

C-54 and 880 Pilots' View of the Ground During Final Approach



C-54 and 880 Pilots' View of the Ground During Flare-out



To generalize flight test results from C-54 to 880 aircraft, a critical requirement is that the cockpit visibility of the 880 must be at least as good as that of the C-54. Figures 1, 2, and 3 reveal that, with both aircraft in a level attitude, 880 visibility is considerably better. Figures 4 and 5 show that, in flight, with the higher nose-up attitude of the 880 taken into account, 880 cockpit visibility is still greater than that of the C-54. Other things being equal, the 880 pilot, at any given point in the final approach, should be able to see more of the approach and runway lighting than the C-54 pilot at the same point.

Flight Profile in the Approach and Landing

A typical ILS approach pattern was abstracted from the data gathered in pilot interviews, task analyses, and flight tests and is presented as Figure 6. As can be seen, the flight path and its relationships to the markers and ILS localizer and glide slope is generally the same for both aircraft. Only the quantitative values for air speed, pitch, rate of descent, etc., are different.

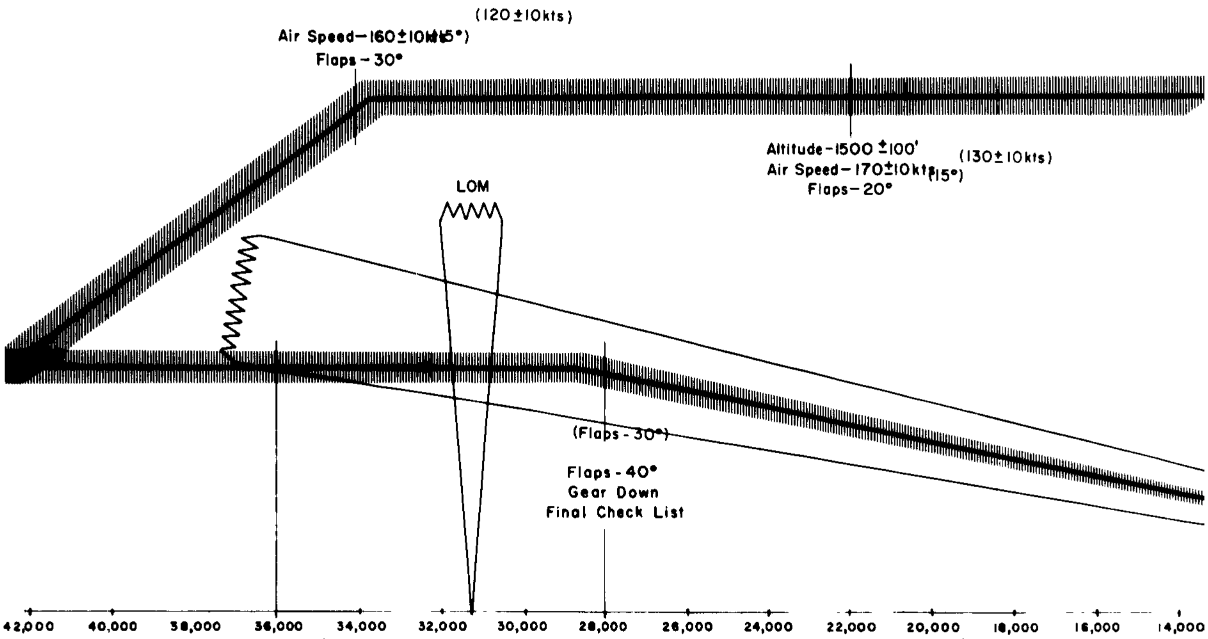
Probably the most obvious difference between the C-54 and 880 aircraft is approach speed. Approach speed of the 880 at maximum gross landing weight is 150 knots while that of the C-54 at its maximum gross landing weight is 110 knots. The implication of this faster rate of approach to the jet pilot's ability to make use of the marks and lights, however, is less obvious and deserves some examination.

It is difficult to see how a faster rate of speed, in and of itself, could make the jet pilot's task in the final approach more difficult. The critical variable in this connection is the amount of time the pilot has in which to interpret the information provided by the marking and lighting and to make the decision as to whether to proceed with the landing or abort the

1

Figure 6

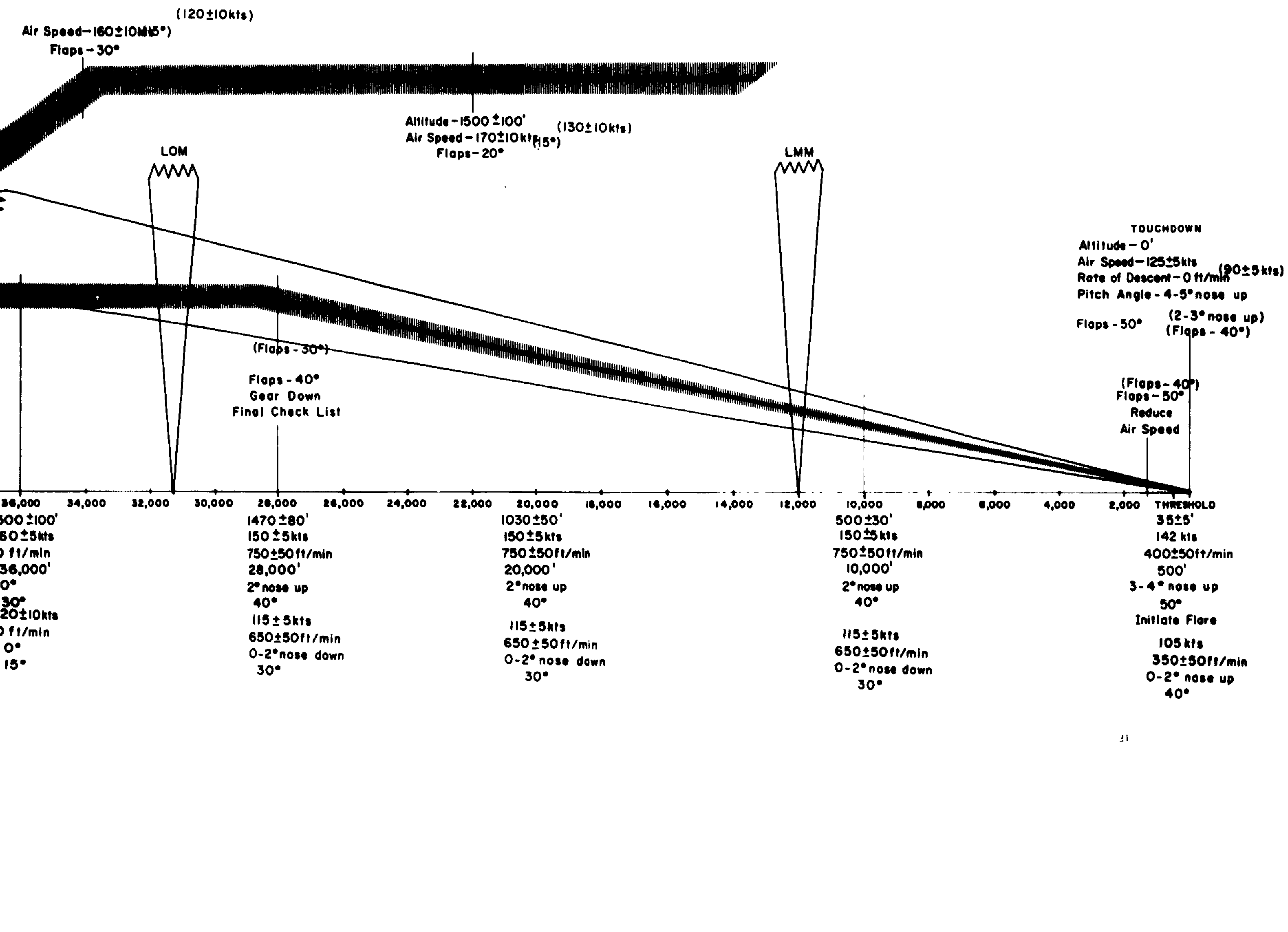
Typical ILS Approach Pattern for the Convair 880 (Gross Weight = 130,00[cut off]
and the Douglas C-54 (Gross Weight = 63,500 Pounds)



	36,000	28,000	20,000
880			
ALTITUDE	1500 ±100'	1470 ±80'	1030 ±50'
AIR SPEED	160 ±5kts	150 ±5kts	150 ±5kts
RATE OF DESCENT	0 ft/min	750±50ft/min	750 ±50ft/min
DISTANCE FROM TOUCHDOWN	36,000'	28,000'	20,000'
PITCH ANGLE	0°	2° nose up	2° nose up
FLAPS	30°	40°	40°
C-54			
AIR SPEED	120±10kts	115 ± 5kts	115 ± 5kts
RATE OF DESCENT	0 ft/min	650±50ft/min	650 ±50ft/min
PITCH	0°	0-2° nose down	0-2° nose down
FLAPS	15°	30°	30°

Figure 6

Typical ILS Approach Pattern for the Convair 880 (Gross Weight = 130,000 Pounds) and the Douglas C-54 (Gross Weight = 63,500 Pounds)



approach. This time variable is clearly a function of approach speed but it is also a function of the visibility conditions which prevail at the time of a given approach.

Jets are presently being certified to land under minimum conditions of 1/2 mile visibility and 200 ft. ceiling. Thus, under minimum conditions, 880 flying time from breakout to touchdown would be approximately 12 seconds. In order to make the C-54 pilot's task comparable to that of the 880 pilot's, research flights in the C-54 should be arranged in such a way that the pilot lifts his hood and "goes contact" with 12 seconds of flying time to the runway remaining. If we extrapolate from the C-54 approach speeds observed in the flight tests, the point at which the research pilot should lift his hood is 2,052 ft. from the runway.

While this procedure should solve, or at least diminish, the problem of approach speed differential it may, at the same time, give rise to another problem. The C-54 pilot may receive slightly better rate-of-closure information than the 880 pilot since the C-54's 12 seconds of visual contact flight are closer to the runway threshold than the 880's 12 seconds. For purposes of this discussion, rate-of-closure information will be defined as the rate of change in visual angle subtended by the runway threshold as the aircraft approaches the runway and it will be assumed that, within limits, faster rates of change in visual angle yield better rate-of-closure information. Figure 7 shows the increase in visual angle subtended by the standard 200 ft. threshold as a function of distance from the threshold. As can be seen, the visual angle increases rapidly in the last 1,000 ft. before reaching threshold. This 1,000 ft. segment accounts for 49% of the C-54 pilot's 12 seconds of visual contact flying and for only 37% of the 880 pilot's 12 seconds. Table 6 shows a second-by-second analysis of the last 12 seconds of the approach in the two aircraft in terms of distance from threshold,

Figure 7.

Visual Angle Subtended by a 200-Foot Runway Threshold as a Function of Distance From Threshold

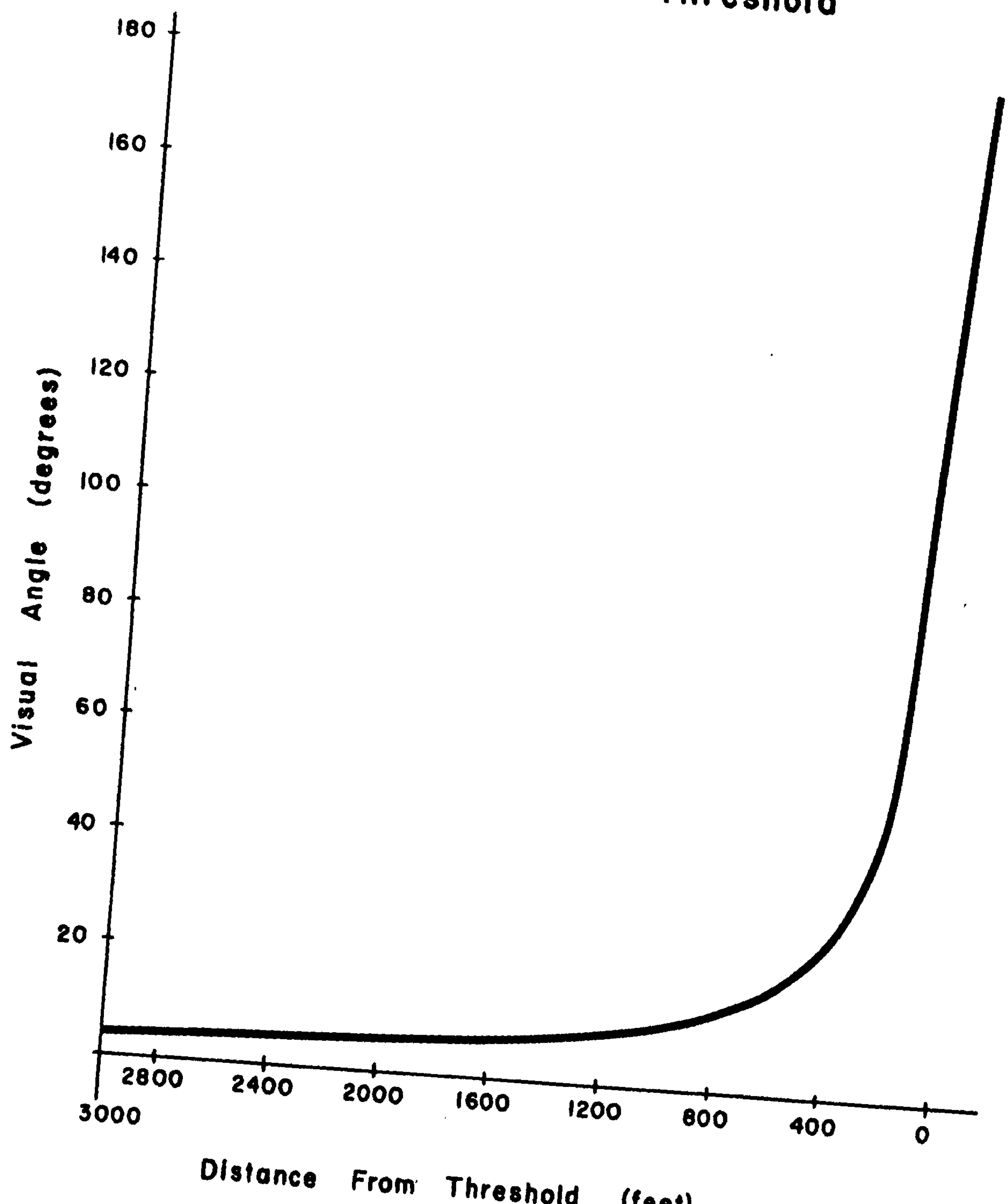


Table 6: Rate of Change in Visual Angle Subtended by a 200 Foot Runway Threshold as a Function of Speed of Approach to the Runway

Time (seconds)	C-54 Distance (feet)	C-54 Visual Angle	C-54 Angular Change per Second	880 Distance (feet)	880 Visual Angle	880 Angular Change per Second
12	2,052	$5^{\circ}40'$		2,700	$4^{\circ}20'$	
11	1,881	6°	$20'$	2,475	$4^{\circ}40'$	$20'$
10	1,710	$6^{\circ}40'$	$40'$	2,250	5°	$20'$
9	1,539	$7^{\circ}20'$	$40'$	2,025	$5^{\circ}40'$	$40'$
8	1,368	$8^{\circ}20'$	1°	1,800	$6^{\circ}20'$	$40'$
7	1,197	$9^{\circ}30'$	$1^{\circ}10'$	1,575	$7^{\circ}20'$	1°
6	1,026	$11^{\circ}10'$	$1^{\circ}40'$	1,350	$8^{\circ}30'$	$1^{\circ}10'$
5	855	$13^{\circ}20'$	$2^{\circ}10'$	1,125	$10^{\circ}10'$	$1^{\circ}40'$
4	684	$16^{\circ}40'$	$3^{\circ}20'$	900	$12^{\circ}40'$	$2^{\circ}30'$
3	513	22°	$5^{\circ}20'$	675	$16^{\circ}50'$	$4^{\circ}10'$
2	342	$32^{\circ}40'$	$10^{\circ}40'$	450	25°	$8^{\circ}10'$
1	171	$60^{\circ}40'$	28°	225	48°	23°
0	0	180°	$119^{\circ}20'$	0	180°	132°
			$\bar{X}=14.53^{\circ}$			$\bar{X}=14.64^{\circ}$

visual angle subtended by the threshold, and the change in visual angle at one-second intervals. This analysis assumes that the approach speeds of the two aircraft are the same as those observed in the aforementioned flight tests; namely, 171 ft. per second for the C-54 and 225 ft. per second for the 880. The information in Table 6 reveals that the differences in mean change in visual angle per second is very small, probably inconsequential, and in favor of the 880 pilot. These figures may be misleading, however, since they include the change in visual angle which occurs during the last second before threshold. Since this increase is of such an extreme magnitude and since touchdown is so imminent, this "last-second" information may be of little or no use to the pilot. Whether or not this is the case is difficult to say in the absence of any empirical data. Recalculation of the means without these last-second figures changes the picture considerably. Mean angular change per second becomes 5.00° for the C-54 and 3.97° for the 880.[1] If, on the basis of judgment or future investigation, these latter rates are taken to be more meaningful indices of rate-of-closure information, then this variable will constitute a limitation on the generality of C-54 evaluative results. One possible solution to this problem would be to scale down objects in the vicinity of the experimental runway. As an example, Table 7 shows visual angles and changes in visual angles for the C-54 pilot approaching a runway with a 152 ft. threshold. These figures are identical to those of the 880 approaching a runway with a 200 ft. threshold.

---

[1] At any given distance from the runway, the rate of change in visual angle will be greater for the 880 pilot than for the C-54 pilot due to the 880's higher approach speed, but for any given instant of time within the context of the 12 seconds of visual contact flight the 880 is further from the runway threshold than the C-54. The visual angle subtended by the runway is therefore smaller and the rate of change in visual angle not as great for the 880 pilot as for the C-54 pilot.

Table 7: Rate of Change in Visual Angle Subtended by a 152 Foot Runway Threshold During a C-54 Approach

Distance (feet)	Visual Angle	Angular Change per Second
2,052	$4^{\circ}20'$	
1,881	$4^{\circ}40'$	$20'$
1,710	5°	$20'$
1,539	$5^{\circ}40'$	$40'$
1,368	$6^{\circ}20'$	$40'$
1,197	$7^{\circ}20'$	1°
1,026	$8^{\circ}30'$	$1^{\circ}10'$
855	$10^{\circ}10'$	$1^{\circ}40'$
684	$12^{\circ}40'$	$2^{\circ}30'$
513	$16^{\circ}50'$	$4^{\circ}10'$
342	25°	$8^{\circ}10'$
171	48°	23°
0	180°	132°

The reader should bear in mind that the foregoing discussion is based on the assumption that, within certain unknown limits, higher rates of change in visual angle yield better rate-of-closure information. While this seems a reasonable assumption there is very little in the way of experimental data to support it. In any event, if the assumption is true then the differential rates of change in visual angle may constitute a limitation on the generality of C-54 evaluative results and reduction of threshold length may be a way to deal with this problem. If the assumption is not true - i. e., if slower rates of change in visual angle yield better rate-of-closure information - then there is no problem. Some research is needed to determine: (1) the direction of the relationship between rate of change in visual angle and rate-of-closure information and (2) the limits within which this relationship holds true.

III. Summary of Recommendations

The implications of the foregoing comparisons for generality of flight test results depend upon which of the two types of evaluation (operational acceptability or field experimentation) the C-54 is to be used for.

If the intention is to use the C-54 to predict the performance of an 880 on a given marking and lighting design, the results of this study indicate that no major problems are likely to be encountered. The general procedure would be to make the research pilot's task as similar as possible to that of the jet pilot. The research pilot should be permitted to use the Flight Director in approaches to the chosen AML design. A correction should be made for the approach speed differences by adjusting the breakout point in such a way as to equalize flying time from breakout to touchdown. Although, by appropriate loading of the C-54, it would be possible to simulate the pitch profile of the 880, this is not recommended inasmuch as the 880, even with its higher nose-up attitude, offers superior cockpit visibility to that of the C-54. Increasing the pitch of the C-54 artificially would only serve to make this discrepancy larger. In addition, the research pilot might be asked to fly much closer tolerances than are customary with the C-54 particularly with respect to air speed and magnitude of roll deviations from the level attitude. With these modifications in flight procedures, one could expect C-54 flight test results to be closely similar to those which would be obtained in a check-out of the same AML design with the 880.

If the C-54 is used as a research tool to establish general relationships between AML design features and pilot-aircraft performance, then procedures should be arranged to insure that the pilot is as busy as possible, consistent with safety, during his approach. As an approximation to this it is recommended that the use of the Flight Director not be permitted and that

the Safety Pilot fly the airplane to a point not more than one-half mile from threshold while the research pilot is under the hood. Further, the aircraft should be offset from the ILS localizer and glide slope when the research pilot takes over. The exact point of breakout and the amount of offset are empirical matters which can be determined through a process of limits testing. It is conceivable that the pilot's excess data-processing capacity will prove to be so great that the amount of offset necessary to exhaust it will be inconsistent with considerations of safety, i.e., the data-processing capabilities of the pilot may exceed the maneuvering capabilities of the aircraft. If this proves to be the case then, of course, the capabilities of the aircraft must be the limiting factors and another approach to the diminution of the pilot's excess capacity must be taken. It is suggested that this can be accomplished by requiring the pilot to perform extraneous data-processing tasks. He can be required to respond to interrogation from the tower, or to monitor certain instruments and report his readings to the tower. These are only examples. There are, undoubtedly, many other tasks which will accomplish the same purpose. In any event, procedures should be such that the pilot is working at full capacity on every experimental approach. If this is done the subject-pilot will be busier than any pilot is likely to be while making an approach under normal operating conditions in any type of aircraft now in service and the differences which exist among the components, design features, and AML designs under evaluation are more likely to be reflected in whatever criterion measures are chosen. If AML designs are developed through flight tests conducted under these conditions with a C-54, the results should be readily generalizable to any commercial aircraft now in use, since the jet pilot's task is well within those limits.

It should be pointed out that a lower level of effort is demanded of the pilot in the operational acceptability test than in the field experimentation type of investigation. It appears obvious, for this reason, that if an AML

design is developed through field experimentation, operational acceptability testing is a less important requirement since the pilot would be flying under less demanding conditions. The operational acceptability test is a valuable technique, however, for checking out AML designs which have been developed through laboratory research, simulator research, or rational, non-empirical methods.

In conclusion, then, close examination of the results of this study reveals no major qualitative differences between the operating routine and performance characteristics of the C-54 and those of the 880. Consequently, there is no reason to suspect that the information requirements are different. There are differences between the two aircraft, to be sure, but they do not seem to be of the sort which would make the visual task of the jet pilot more difficult or reduce the effectiveness with which he makes use of the airport marking and lighting. In effect, the picture which emerges from the results of this research is that of the C-54 and the modern commercial jet carrier as two variations on a single theme. The basic similarities far outweigh the differences. They are both fixed-wing aircraft. They describe the same basic flight path in the approach and landing. They use the same ground-based guidance equipment on instrument approaches. They are controlled on the same rotational and translational dimensions. Procedures with respect to flap configuration and relative air speed adjustments during the approach and landing are the same for both aircraft. Above all, the pilot's task is essentially the same visual compensatory tracking task regardless of whether he is flying the C-54 or the Convair 880.

The question at issue here - that of general applicability of evaluative results - is one which primarily concerns the relationship between the pilot's eyes and the marks and lights on the ground. The marks and lights provide the stimuli to which the pilot responds in controlling his aircraft. Careful

examination of the two types of aircraft and the demands which they make on the pilot has revealed no reason to expect that the information which the jet pilot requires from the marks and lights will be different as a function of the aircraft around him.

We conclude that, through research with the C-54, alternative AML designs can be, at least, ranked in terms of effectiveness and that this ranking will very probably hold for the Convair 880 and other high-performance aircraft. We further conclude that, with careful attention to the details of the experimental design, evaluations which are generally applicable to all commercial aircraft now in service can be conducted without the considerable expense of installing in an 880 the complex instrumentation which is already available in the NAFEC C-54.

APPENDIX A

SOURCES OF INFORMATION

<u>Documents</u>

1. Air Traffic Control Procedures. Atlantic City, N.J.: Federal Aviation Agency, Air Traffic Service, November 1, 1961. (ATM-2-A, Revision 6).

2. C-54 Flight Manual. Atlantic City, N. J.: Federal Aviation Agency, March 31, 1959.

3. Convair 880 FAA Approved Airplane Flight Manual. Atlantic City, N. J.: Federal Aviation Agency, May 13, 1960. (Document No. CS-59-019).

4. DC-8 Flight Study Guide. Santa Monica, Calif.: Douglas Aircraft Co., Inc., April 1, 1960.

5. Devlin, R. A. Airbourne Measurement Facilities Available in C-54G (NAFEC) Aircraft. Atlantic City, N. J.: National Aviation Facilities Experimental Center, Federal Aviation Agency.

6. FAA Approved Airplane Flight Manual - Boeing 707 Stratoliner. Renton, Washington: Boeing Airplane Co., December 3, 1959. (Document No. D6-1563).

7. FAA. Provided Binocular Photographs Taken from the Position of the Pilot's Eyes, Showing the Visual Angles Subtended by the Windscreens of the Following Aircraft:

   a. Douglas C-54
   b. Convair 880
   c. Douglas DC-8
   d. Boeing 707

8. Gannett, J. R. 707 Pilot Training Manual. Renton, Washington: Boeing Airplane Co., November 20, 1959. (Document No. D6-3529).

9. Operations Manual - Boeing 707 Stratoliner. Renton, Washington: Boeing Airplane Co., Transport Division, June 1, 1959. (Document No. D6-1456-2).

10. TWA Boeing 707 Pilot Study Guide for Proficiency Training. TWA Transportation Training Center, September 30, 1960. (Document No. FT 167A).

11. TWA Convair 880 Pilot Study Guide for Proficiency Training. TWA Transportation Training Center, May 10, 1961. (Document No. FT 168A).

12. TWA Piston Pilot Flight Instructor's Guide #1. TWA Transportation Training Center, December 13, 1961.

Interviews

1. Franco, Capt. V. N., Northeast Airlines.

2. Frier, Capt. J. A., Director of Flight Training, TWA Transportation Training Center.

3. Grainger, Capt. R., Slick Airways.

4. Graybill, Capt. T. R., Manager of Flight Instruction, TWA Transportation Training Center.

5. Loranger, Capt. R. O., Chief Pilot, Northeast Airlines.

6. Morgan, Capt. R. A., Slick Airways.

7. Ogilvie, A. W., Manager of Simulator Maintenance and Engineering, TWA Transportation Training Center.

8. Remick, Capt. R. A., Northeast Airlines.

9. Seib, Capt. P. G., Chief Pilot, East Coast Operations, Slick Airways.

10. Willard, Capt. C., Northeast Airlines.

11. Zadwick, Capt. I. S., Slick Airways.

APPENDIX B
FLIGHT TEST PROCEDURES AND RESULTS

Comparative performance data were collected during test flights with the Douglas C-54 and a Convair 880 owned by the FAA. A total of 22 simulated ILS approaches was flown in the two aircraft with pilots hooded from the time the outer marker light on the instrument panel went on until the middle marker was reached. The hood permitted the pilot to view the instrument panel but blocked his view of the windscreen. The C-54 pilots removed the hood when the middle marker light on the instrument panel went off (approximately one-half mile from threshold); the 880 pilots removed it when the middle marker light went on (about 3/4 mile from threshold). The distances were selected in order to simulate breakouts at weather minima appropriate to the two aircraft. The high sensitivity setting was used for reception of the outer marker signal and low sensitivity was used for the middle marker signal. Therefore, to the extent that there was error in time of beacon signal reception, the hood was put on early and removed late.

Each of the two C-54 pilots flew six approaches; three from the left seat using the Flight Director, and three from the right seat without it for a total of twelve C-54 approaches. All 880 approaches were flown from the left seat (one pilot flew 5 approaches, the pilots changed seats, and the second pilot flew 5 approaches) and each of the two pilots flew 4 approaches with the Flight Director display on the ILS setting and one approach with the display on the Heading setting. On the ILS setting radio signals from the ILS localizer and glide slope are used to compute error in the flight path and the cockpit display indicates, by the orientation of a bar, the direction and degree of bank

necessary to intercept the glide slope and localizer. On the Heading setting, the display does not respond to ILS signals. A needle indicates a heading to steer to stay on a pre-selected line of flight.

An experimenter rode in the jump seat of each aircraft during all flights in order to assure that experimental procedures were followed exactly. Touch-and-go landings were made for six 880 and seven C-54 approaches after which a malfunction in the recording equipment caused a one-hour delay in the tests. By the time the tests were resumed, a 15-knot tailwind down the runway had developed. After this, low passes to an altitude of about 10 feet were made. Approach profiles and ground tracks were recorded on a time base with phototheodolites. Pitch and roll were recorded by means of on-board measuring equipment. The theodolites and the on-board gyros were operated on each trial from the time the aircraft crossed the outer marker until it touched down and took off for its next trial. With respect to aircraft gross weight, the 880 varied from 137,000 pounds at the beginning of the experiment to 105,000 at the end while the C-54 went from 56,600 to about 50,000 pounds.

Pilot experience, flight test sequence, and flight test results are presented in Tables B-1 through B-11 below. Additional flight test results are presented in Tables 1 through 5 in the body of the report.

Table B-1: C-54 Test Pilot Experience

	Test Pilot A	Test Pilot B
Total Flying Time	13,000 hrs.	13,000 hrs.
Multi-Engine Reciprocating Time	9,000 hrs.	11,000 hrs.
C-54 Time	800 hrs.	1,600 hrs.

Table B-2: 880 Test Pilot Experience

	Test Pilot A	Test Pilot B
Total Flying Time	4,600 hrs.	7,000 hrs.
Multi-Engine Jet Time	150 hrs.	2,500 hrs.
880 Time	100 hrs.	350 hrs.

Table B-3: Flight Test Sequence

Approach	Aircraft	Pilot	Seat	Flight Director
#1	C-54	A	Left	Yes
2	880	C	Left	Yes
3	C-54	B	Right	No
4	880	C	Left	Yes
5	C-54	A	Left	Yes
6	880	C	Left	Yes
7	C-54	B	Left	No
8	880	C	Left	Yes
9	C-54	A	Left	Yes
10	880	C	Left	No
(880 landed - dropped off film - pilots change seats)				
11	C-54	B	Right	No
12	C-54	B	Left	Yes
13	880	D	Left	Yes
(test delayed 1.75 hours for attempted correction of antenna difficulties with 880)				
14*	C-54	A	Right	No
15	880	D	Left	Yes
16	C-54	B	Left	Yes
17	880	D	Left	Yes
18	C-54	A	Right	No
19	880	D	Left	Yes
20	C-54	B	Left	Yes
21	880	D	Left	No
22	C-54	A	Right	No

* No touchdown on Runs #14 to 22 because of excessive tailwind (11 to 18 knots).

Table B-4: Additional Flight Test Results

	C-54	880	df	t	p
Range of pitch deviations					
Middle marker to threshold	9.6°	2.6°	21	3.30	$<.01$
Threshold to touchdown	2.7°	$.3^{\circ}$	17	44.44	$<.001$
Roll					
Deviation from level at breakout	1.6°	1.1°	21	.86	$>.1$
Frequency of deviations (MM-TD)	2.2	2.9	21	1.23	$>.1$
Magnitude of deviations (MM-TD)	3.3°	1.9°	56	3.11	$<.01$
Flying time from breakout to threshold	15.4 sec.	17.6 sec.	21	10.11	$<.001$

Table B-5: C-54 Pitch Data

Trial	3 Miles	MM	Threshold	Flare	Range of Pitch Deviations	
					MM-T	T-TD
1	3^{o} down	6^{o} down	0^{o}	2^{o} up	10^{o}	3^{o}
2	3^{o} up	2^{o} up	1^{o} up	2^{o} up	14^{o}	2^{o}
5	5^{o} down	1^{o} down	3^{o} up	6^{o} up	9^{o}	3^{o}
7	0^{o}	0^{o}	0^{o}	1^{o} up	9^{o}	2^{o}
9	4^{o} up	0^{o}	2^{o} up	2^{o} up	5^{o}	1^{o}
11	2^{o} up	2^{o} up	3^{o} down	0^{o}	7^{o}	3^{o}
12	1^{o} up	1^{o} up	0^{o}	1^{o} up	4^{o}	3^{o}
14	0^{o}	1^{o} up	2^{o} up	4^{o} up	5^{o}	
16	2^{o} up	1^{o} up	0^{o}	1^{o} up	5^{o}	
18	1^{o} up	9^{o} down	2^{o} up	2^{o} up	20^{o}	
20	1^{o} down	0^{o}	1^{o} up	2^{o} up	7^{o}	
22	3^{o} down	15^{o} down	4^{o} up	4^{o} up	25^{o}	

Table B-6: 880 Pitch Data

Trial	3 Miles	MM	Threshold	Flare	Range of Pitch Deviations	
					MM-T	T-TD
2	2° up	2° up	4° up	5° up	3°	1°
4	2° up	2° up	5° up	5° up	3°	1°
6	1° up	3° up	4° up	4° up	2°	0°
8	0°	3° up	4° up	4° up	2°	0°
10	1° up	0°	4° up	4° up	5°	0°
13	2° up	3° up	3° up	4° up	1°	0°
15	1° up	1° up	2° up		2°	
17	0°	1° up	4° up		4°	
19	2° up	0°	2° up		2°	
21	4° up	0°	2° up		2°	

Table B-7: Roll Deviation at Breakout

C-54		880	
Trial	Roll	Trial	Roll
1	0°	2	0°
3	2° left	4	0°
5	3° left	6	1° left
7	1° right	8	0°
9	1° left	10	0°
11	2° left	13	4° right
12	1° left	15	1° right
14	0°	17	0°
16	4° left	19	4° left
18	2° left	21	1° right
20	3° left		
22	1° left		

Table B-8: Frequency of Roll Deviations from Middle Marker to Touchdown

C-54		880	
Trial	Frequency	Trial	Frequency
1	2	2	1
3	3	4	2
5	2	6	4
7	3	8	2
9	2	10	1
11	4	13	3
12	4	15	7
14	1	17	3
16	2	19	3
18	1	21	3
20	2		
22	1		

Table B-9: Magnitude of Roll Deviations from Middle Marker to Touchdown

C-54		880	
Trial	Roll	Trial	Roll
1	6^o left 2^o right	2	1^o left
3	4^o left 2^o right 2^o left	4	2^o left 1^o right
5	3^o left 3^o right	6	1^o left 1^o right 1^o left 1^o right
7	1^o right 3^o left 3^o right	8	1^o right 2^o left
9	4^o left 4^o right	10	6^o right
11	2^o left 1^o right 5^o left 4^o right	13	4^o right 2^o left 1^o right

Table B-9 (Cont.)

C-54		880	
Trial	Roll	Trial	Roll
12	2^o left 1^o right 6^o left 4^o right	15	1^o right 1^o left 2^o right 1^o left 2^o right 3^o left 1^o right
14	6^o left	17	2^o left 1^o right 1^o left
16	7^o left 1^o right	19	4^o left 3^o right 1^o left
18	9^o left	21	4^o right 3^o left 1^o right
20	4^o left 1^o right		
22	3^o left		

Table B-10: Deviations from Localizer at Breakout

C-54		880	
With F.D. (feet)	Without F.D. (feet)	With F.D. (feet)	Without F.D. (feet)
16.0	64.0	28.0	236.0
26.4	72.0	20.8	120.0
84.0	56.0	36.0	
44.0	160.0	10.4	
13.6	160.0	50.4	
89.6	335.2	5.6	
	244.0	48.0	
		8.0	

Table B-11: Deviations from Glide Slope at Breakout

C-54		880	
With F.D. (feet)	Without F.D. (feet)	With F.D. (feet)	Without F.D. (feet)
16.00	44.80	38.40	22.40
19.20	14.72	41.60	28.80
19.20	25.60	9.60	
12.80	35.20	28.80	
12.80	28.80	4.48	
48.64	3.20	0.00	
	12.80	8.32	
		21.12	

APPENDIX C

TABULAR PRESENTATION OF PILOT TASK ANALYSES

This section describes the pilot's tasks, information requirements, and possible sources of information for three phases of the approach and landing. The three phases are distinguished in terms of the objective to be achieved and the pilot's control and information-processing tasks as follows:

Final approach on localizer course. This phase begins when the ILS localizer signal is intercepted and the pilot begins maneuvering to establish the aircraft on the proper heading. It terminates when ILS glide slope signal is intercepted.

Final approach on glide slope. This phase begins when the ILS glide slope signal is intercepted and terminates at the initiation of the flare-out. The pilot's task is to establish the proper rate of descent and to control air speed within relatively close tolerance limits during the descent.

Flare-out and touchdown. This phase begins with the initiation of the flare-out and terminates when the landing gear makes contact with the runway. The pilot's task is to raise the nose of the aircraft in order to decrease rate of descent and air speed sufficiently to permit touchdown within the first one-third of the runway length.

A breakdown of specific control tasks which the pilot must perform is presented for each phase. For each control task there are specified the parameters which are controlled, the permissible range of values of the parameters, the controls used, the information required to perform the task, and the possible sources of information, both intra-cockpit and extra cockpit.

The tables were constructed to give a description of the 880 pilot's task. Information about the C-54 pilot's task is given in parentheses where there are differences between the two aircraft.

FINAL APPROACH ON LOCALIZER COURSE

Phase Objective: To establish position for initiation of descent on ILS glide slope.	General Task: 1. Establish heading on ILS localizer. 2. Maintain a straight-in approach.
Initiating Conditions: Intercept of ILS localizer Altitude: 1500 ± 100 ft. Air speed: 160 ± 5 knots (120 ± 10 knots) Altitude: Pitch - level Roll - level Yaw - none, or necessary degree to counter crosswind Distance: 36,000 ft. from touchdown	Terminating Conditions: Intercept of ILS glide slope Altitude: 1500 ± 100 ft. Air speed: 160 ± 5 knots (120 ± 10 knots) Altitude: Pitch - level Roll - level Yaw - none, or necessary degree to counter crosswind Distance : 28,600 ft. from touchdown

Specific Task	Stored or Recommended Parameter Values & Tolerances	Control	Information: Information Required	Information: Internal Source	Information: External Source
Manipulate ailerons to align heading with ILS localizer		Control wheel	Deviation from localizer and rate of change in deviation	Flight Path Indicator Flight Director Command Bar	(Position of runway re: windscreen
Adjust elevators and horizontal stabilizers to maintain altitude	1500 ± 100 ft.	Control column and stabilizer trim switch (Elevator trim wheel)	Deviation from desired altitude and rate of change in deviation	Altimeter Rate of Climb Indicator	(Apparent size and shape of ground objects in airport area)
Adjust throttles to maintain desired air speed	160 ± 5 knots (120 ± 10 knots)	Throttles	Air speed	Air Speed Indicator	Sound of engines
Adjust elevator and horizontal stabilizer to maintain appropriate pitch attitude	Pitch: level or degree necessary to maintain altitude	Control column and stabilizer trim switch (Elevator trim wheel)	Degree of pitch Deviation from null	Horizon Director Indicator	
Adjust ailerons to maintain appropriate roll attitude	Roll: level or necessary degree to align flight path with localizer	Control wheel	Degree of roll Deviation from null	Flight Director Command Bar Bank and Turn Indicator Flight Path Indicator	(Change in position of ground pattern re: windscreen)
Adjust rudders to maintain appropriate yaw attitude	Yaw: none or necessary degree to counter crosswind	Rudder pedals	Deviation from null		

Note: External Information Sources in parentheses are for VFR conditions only. Other items in parentheses indicate C-54 values which differ from those of the 880.

FINAL APPROACH ON GLIDE SLOPE*

Phase Objective	General Task
To establish position for flaring at proper distance from point of touchdown. **	1. Establish an appropriate glide angle and rate of descent. 2. Maintain a straight-in approach.
Initiating Conditions: Intercept of ILS glide slope. Altitide: 1500 ± 100 ft. Air speed: 160 ± 5 knots (120 ± 10 knots) Course: Straight Attitude: Pitch - level Roll - level Yaw - none, or necessary degree to counter crosswind Distance: 28,600 ft. from touchdown	**Terminating Conditions:** Arrival at runway threshold. Altitude: 50 ± 3 ft. Air speed: 142 ± 5 knots (105 ± 5 knots) Course: Straight Attitude: Pitch - 2-3° nose up (0-2° nose up) Roll - level Yaw - none, or necessary degree to counter crosswind Distance: 500 ft. from touchdown

Specific Task	Stored or Recommended Parameter Values & Tolerances	Control	Information: Information Required	Information: Internal Source	Information: External Source
Give orders (executed by co-pilot) for 40° flaps and landing gear down	Flaps - 40° (30°) Landing gear - down and locked	Flap lever	Aircraft position relative to glide slope intercept	Flight Path Indicator	(Apparent size and shape of runway pattern)
Adjust elevators and horizontal stabilizers to initiate descent on glide slope	Descent initiated when ILS glide slope is intercepted	Control column and stabilizer trim switch (Elevator trim wheel)	Time of glide slope intercept Deviation from glide slope	Flight Path Indicator Flight Director Command Bar	
Adjust throttles to reduce air speed	150 ± 5 knots (115 ± 5 knots)	Throttles	Air speed	Air Speed Indicator	Sound of engine (Rate of movement of ground objects in visual field)
Adjust elevators and horizontal stabilizers to maintain constant rate of descent	700-800 ft/min (600-700 ft/min)	Control column and stabilizer trim switch (Elevator trim wheel)	Rate of descent	Rate of Climb Indicator	(Glide angle constant: apparent ground speed will change. Rate of flow of expansion pattern will change)
Adjust ailerons to maintain heading		Control wheel	Deviations from ILS localizer	Flight Path Indicator Flight Director Command Bar	(Apparent lateral movement of aiming point on runway re: windscreen)

Note: External Information Sources in parentheses are for VFR conditions only.

* Visual contact with the runway is assumed to occur during this phase of the approach. Jet weather minima are 300 ft. ceiling and 3/4 mile visibility. C-54 minima are 200 ft. ceiling and 1/2 mile visibility.

** This is dependent upon gross weight of the aircraft, air speed, rate of descent, and prevailing wind conditions.

FLARE-OUT AND TOUCHDOWN

Phase Objective: To touchdown smoothly on first 1/3 of runway.	**General Task:** 1. Descend to zero altitude. 2. Decrease rate of descent and air speed. 3. Maintain correct heading.
Initiating Conditions: Arrival at runway threshold. Altitude: 50 ± 3 ft. Air speed: 142 ± 5 knots (105 ± 5 knots) Course: Straight Attitude: Pitch - 2-3° nose up (0-2° nose up) Roll - level Yaw - none, or necessary degree to counter crosswind Distance: 500 ft. from touchdown	**Terminating Conditions:** Touchdown. Altitude: zero ft. Air speed: 125 ± 5 knots (90 ± 5 knots) Course: Straight Attitude: Pitch - 4-5° nose up (2-3° nose up) Roll - level Yaw - none, or necessary degree to counter crosswind Distance: zero ft. (Touchdown)

Specific Task	Stored or Recommended Parameter Values & Tolerances	Control	Information: Information Required	Information: Internal Source	Information: External Source
Adjust elevators to pull nose of aircraft up and initiate flare	Pitch-4-5° nose up (2-3° nose up) Flare initiated between threshold and 300 ft. down runway.	Control column	Position of aircraft relative to desired touchdown point. Rate of closure with desired touchdown point.	None	Apparent size and shape of runway pattern. Rate of radial expansion pattern.
Adjust throttles to reduce air speed	Cross threshold at 142 ± 5 knots (105 ± 5 knots). Touchdown at 125 ± 5 knots (90 ± 5 knots)	Throttles	Air speed	Air Speed Indicator	Apparent ground speed
Adjust ailerons to maintain appropriate roll attitude	Roll-level	Control wheel	Roll attitude of aircraft	Horizon Director Indicator. Bank and Turn Indicator.	Rotation of ground plane re: windscreen
Adjust rudders to maintain appropriate yaw attitude	Yaw-none, or necessary to counter crosswind	Rudder pedals	Yaw attitude of aircraft		Apparent horizontal movement of objects from null position re: windscreen